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Geology and mineralization of the Minerva Mine No. 1, Hardin County, Illinois

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GEOLOGY AND MINERALIZATION OF THE MINERVA MINE NO. 1, HARDIN COUNTY, ILLINOIS

BY

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A

THESIS

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INTRODUCTION

Purpose of investigation:

This study originally was undertaken to describe the witherite identified in specimens collected at the Minerva Oil Company Mine No. 1, Hardin County, Illinois. The original specimens of witherite were collected on October 25, 1948, by Charles E. Tothill, while on a senior trip through the fluorspar mine. The witherite was identified by Dr. O. R. Grawe, Chairman of the Geology Department, Missouri School of Mines, Rolla, Missouri, to whom the specimens were presented. Dr. Grawe suggested that the writer visit the southern Illinois fluorspar area to determine the occurrence and distribution of the witherite. This mineral had been described previously from a limited number of localities in the United States and in the world, but had not been described from the fluorspar district of southern Illinois.

The study was extended to describe the geology and mineralization of the Minerva Mine No. 1. This mine is the most recently developed producing fluorspar mine in the Cave in Rock district of southern Illinois.

Conditions under which the work was done:

Field work was completed during 15 days which were spent in the Hardin County area. The first trip to the fluorspar district was taken from December 26, 1948, to

January 3, 1949. During this period, the drift level geology of the Minerva Mine No. 1 was mapped, and samples for laboratory study were collected. From April 8, 1949, to April 13, 1949, other mining properties in the Cave in Rock area, Hardin County, Illinois, were visited. The geology and mineralogy of these mines were compared with that of the Minerva Mine No. 1. From May 31, 1949, to June 5, 1949, surface expression of geologic structures observed in the Minerva Mine No. 1 workings were sought.

Laboratory study was conducted in the Geology Department, Missouri School of Mines, Rolla, Missouri. Rock and mineral specimens collected were studied megascopically and microscopically. X-ray diffraction patterns of unknown minerals were run. In addition, qualitative chemical methods of analysis were employed where necessary for the identification of mineral species.

Summary of previous work:

Numerous descriptions of the occurrence of fluorspar in the Illinois-Kentucky fluorspar district have been published. Extensive geological studies also have been completed.

The earliest published description of the occurrence of fluorite in the Illinois fluorspar district appeared as notices in the first, second, and third volumes of the American Journal of Science, published in 1818, 1820, and 1821.[1]

(1) Amer. Jour. Sci., 1st ser., Vol. 1, pp 52-53, 1818; Vol. 2, pp 178, 1820; Vol. 3, p 243, 1821.

In 1819, Schoolcraft[2] described the occurrence of "fluate

(2) Schoolcraft, Henry R., "A View of the Lead Mines of Missouri", New York, p. 191, 1819.

of lime" near Cave in Rock, Illinois. The "fluate of lime" was found in abandoned diggings embedded in a stiff red clay. A second description by Schoolcraft[3] referred to the

(3) Schoolcraft, Henry R., "Travels in the Central Portions of the Mississippi Valley", U.S.I.A., New York, pp 189-196, 1825.

"fluate of lime" as the "detritus of pre-existing veins". This was followed in 1852 by Brush's[4] description of a fluorspar occurrence in Gallatin County, Illinois.

(4) Brush, G. J., "Note on the Fluorspar Locality of Gallatin County, Illinois", Am. Jour. Sci., 2nd ser., Vol. 14, p. 112, July, 1852.

Worthen,[5] in 1866, described fluorspar vein occurrences in

(5) Worthen, A. H. and Engelmann, George, "Geology of Illinois, Hardin County", Geol. Survey of Illinois, Vol. 1, pp 350-375, 1866.

Hardin County, and Emmons,[6] in 1893, described the occurrence of vein fluorspar near Rosiclare, Illinois. E. O.

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(6) Emmons, S. F., "Fluorspar Deposits of Southern Illinois" Trans. Am. Inst. Min. Eng., Vol. 21, pp 31-53, 1893.

Ulrich and Tangier Smith,[7] in 1905, included an historical

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(7) Ulrich, E. O. and Smith, W. S. Tangier, "Lead, Zinc, and Fluorspar Deposits of Kentucky", U.S.G.S. Professional Paper, No. 36, p. 18, 1905.

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summary of described fluorspar occurrences in southern Illinois and Kentucky in their report on the Kentucky deposits. In 1904, Bain[8] wrote a brief note concerning the

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(8) Bain, H. F., "Fluorspar Deposits of the Kentucky-Illinois District", Mines and Minerals, Vol. 25, No. 4, pp 182-183, November, 1904.

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vein fluorspar deposits in the Kentucky-Illinois district, and a year later, he[9] described the geology of the fluor-

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(9) Bain, H. F., "The Fluorspar Deposits of Southern Illinois", U.S.G.S. Bull. 255, 1905.

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spar deposits of southern Illinois in greater detail. He called attention to the bedded or sheet deposit of fluorspar at the Lead Hill Mine, in the Cave in Rock district and concluded that the fluorine was introduced along horizontal bedding planes and metasommatically replaced the calcite in the Fredonia limestone beneath the Rosiclare sandstone.

In 1920, Weller,(10) in collaboration with Butts,

(10) Weller, Stuart; Butts, Charles; Currier, L. W.; and Salisbury, R. D.; "The Geology of Hardin County", Illinois State Geological Survey, Bull. 41, 1920.

Currier, and Salisbury, published the Geology of Hardin County, the economic geology involving the fluorspar, lead, and zinc in Hardin County being treated by Currier and Butts. The geology of the vein deposits, bedding replacement deposits, and residual deposits was described.

Spurr,(11) in 1926, considered genetic problems of the

(11) Spurr, J. E., "The Kentucky-Illinois Ore-Magmatic District", E.&M.J., Vol. 122, No. 18, pp 695-699, October 30, 1926; Vol. 122, No. 19, pp 731-738, Nov. 6, 1926.

Illinois-Kentucky fluorspar vein and bedding replacement deposits. In 1928, Schwerin(12) described the bedding re-

(12) Schwerin, M., "An Unusual Fluorspar Deposit", E.&M.J., Vol. 126, No. 9, pp 335-339, Sept. 1, 1928.

placement fluorspar deposit adjacent to the Spar Mountain Mining Company property in the Cave in Rock area, and

Bastin,[13] in 1931, described the vein and bedding replace-

(13) Bastin, E. S., "The Fluorspar Deposits of Hardin and Pope Counties, Illinois", Illinois State Geological Survey, Bull. No. 58, 1931.

ment fluorspar deposits and suggested that the banded or "coon-tail" ore was the expression of diffusion banding. Currier,[14] in 1935, discussed the structural setting of the

(14) Currier, L. W., "Structural Features of the Illinois-Kentucky Field", Wash. Acad. Sci. Jour., Vol. 25, No. 11, pp 505-506, Nov. 15, 1935.

fluorspar deposits and took exception to Bastin's theory of "diffusion banding" for the development of the "coon-tail" ore. In 1937, Currier[15] attributed the formation of this

(15) Currier, L. W., "Origin of the Bedding Replacement Deposits of Fluorspar in the Illinois Field", Econ. Geol., Vol. 33, No. 3, pp 364-386, 1937.

banded ore to replacement of limestone by fluorite with the preservation of the bedding and cross-bedding of the rock. The field investigations by Currier[16] with the collabora-

(16) Currier, L. W. and Wagner, Jr., O. E., "Geology of the Cave in Rock District", U.S.G.S. Bull. 942, Part 1, 1944

tion of O. E. Wagner, Jr., carried out in 1934 and 1935, were published in detail in 1944. This is the most recent publication concerning the fluorspar deposits under consideration.

LOCATION AND ACCESSIBILITY

The Minerva Oil Company Mine No. 1 is located in the SE¼ of Section 24, T11S, R9E, five miles north of Cave in Rock, Hardin County, Illinois. The location of the mine is shown on Figure 1. The mine is one mile east of Illinois highway No. 1, a black topped north-south artery. The Minerva Oil Company has 3,000 acres of land in this vicinity. Previously known bedding replacement fluorite occurrences which characterize the Cave in Rock district of the Illinois-Kentucky fluorspar area, and which have been described by Currier,[17] are located southwest of the land-holdings acquired by the Minerva Oil Company.

(17) Currier, L. W. and Wagner, Jr., O. E., Op. cit. pp 55-65

EXPLORATION AND DEVELOPMENT

J. H. Steinmesch, following Currier's idea of the dependency of fluorspar mineralization to northeasterly trending fractures, inaugurated an exploratory churn drilling program by the Minerva Oil Company in 1939 to extend the apparent northeasterly trend of the known Cave in Rock bedding replacement deposits. By 1942,[18] more than one

(18) U.S.B.M., War Minerals Report No. 118, "Zinc-Fluorspar Property of the Minerva Oil Company, Cave in Rock, Hardin County, Illinois."

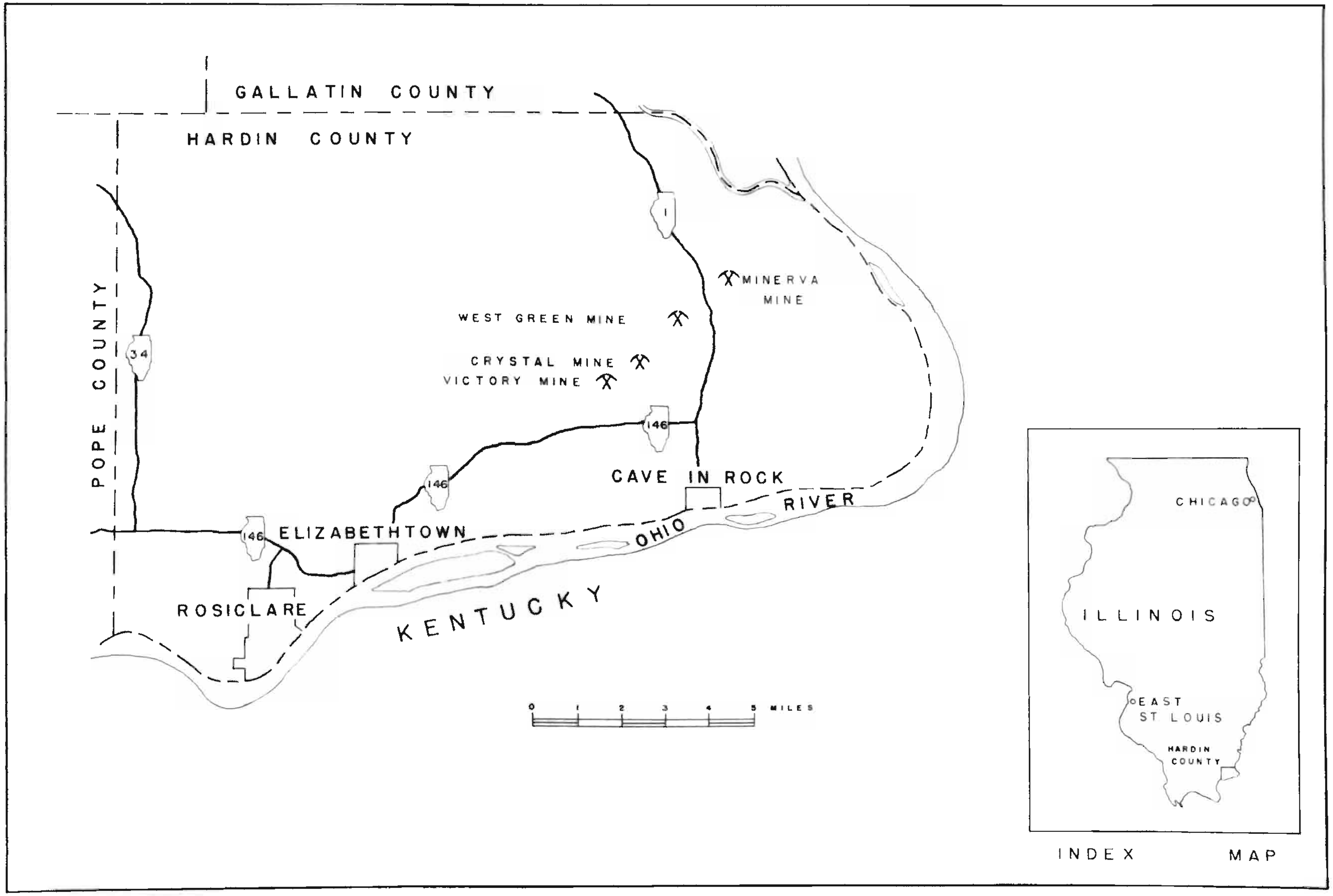


FIGURE I, LOCATION MAP, HARDIN COUNTY, ILLINOIS hundred holes had been drilled, and a deposit of 311,000 tons containing 5.47% zinc and 37.1% fluorspar and 219,000 tons containing 3.33% zinc and 20.53% fluorspar was outlined. A mineralized zone was intersected in the Renault formation of Chester age and another in the underlying Levias and Fredonia members of the Ste. Genevieve formation.

Following the exploration program, development work was undertaken. A shaft, sunk to a depth of 645 feet was completed in 1943. From this shaft, haulage drifts were driven and ore passes were completed to the ore horizon. A 250 ton selective flotation mill was constructed to produce zinc and fluorspar concentrates and by March, 1944, the mine was in daily production. A room and pillar method of ore extraction is employed.

DESCRIPTIVE GEOLOGY

GENERAL STRATIGRAPHY

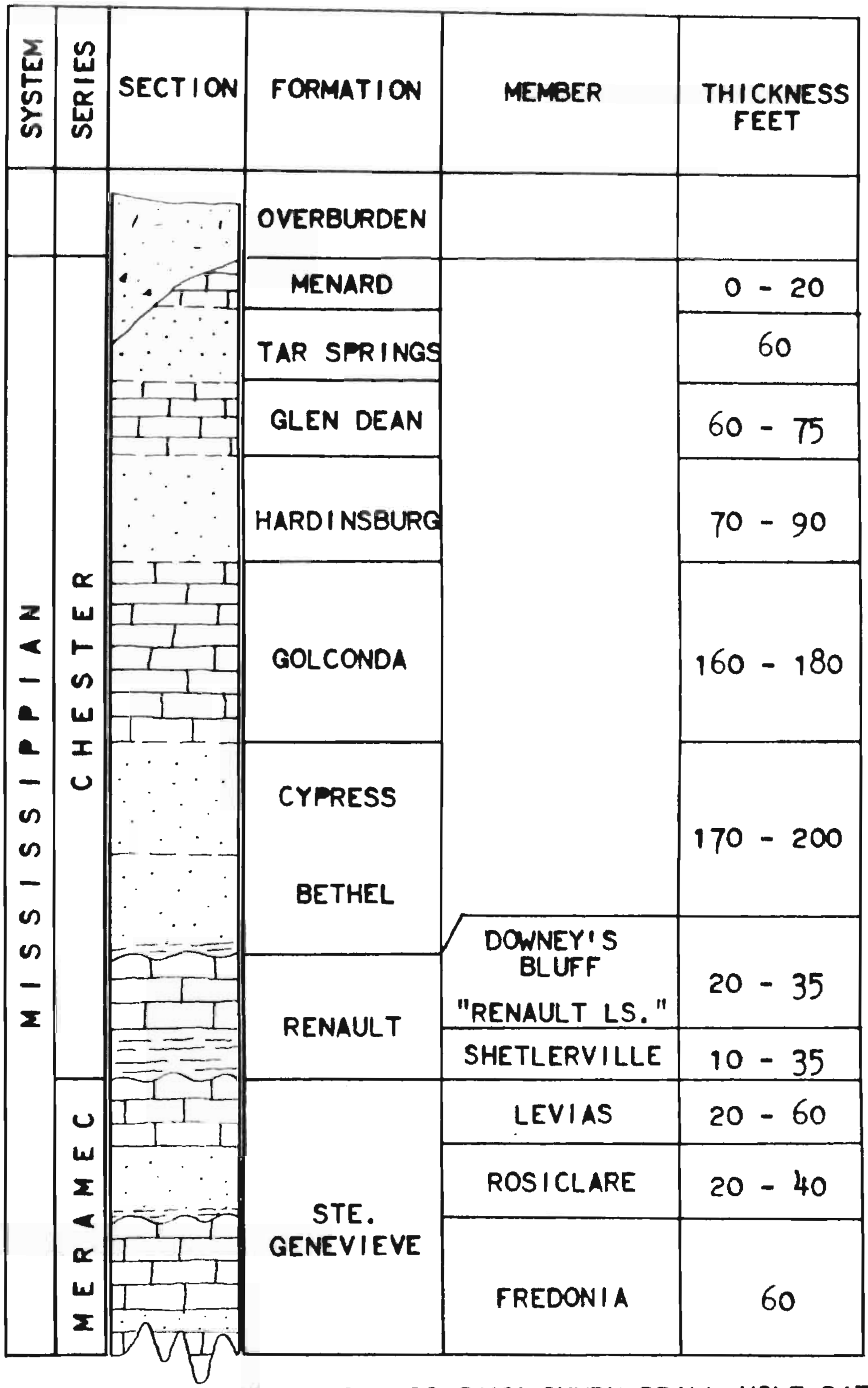
In the Cave in Rock district, the rocks exposed at the surface are sediments of Mississippian and Pennsylvanian age. The strata strike approximately N.70° W. and dip homoclinally to the northeast. The average dip ranges from 3° - 5°.

The oldest formation exposed in the Cave in Rock district, here defined as including all of Hardin County east of the Peters Creek faults, is the Fredonia limestone of Mississippian age. The youngest formation which outcrops in the northern portion of the Cave in Rock district is the Caseyville conglomerate of Pennsylvanian age.

The stratigraphy of the Minerva Oil Company Mine No. 1 was obtained from churn drill hole records.(19) The formations intersected by the drill holes are shown in Figure 2.

(19) Courtesy of the Minerva Oil Company.

In the vicinity of the Minerva Mine No. 1, the Tar Springs sandstone and the overlying Menard limestone, both of Mississippian age, underlie the surface soil. The shaft of the Minerva Mine is bottomed in the Levias limestone, which is of upper Ste. Genevieve, Meramec age. The drift level workings are in the Levias limestone and in the over-



COMPILED FROM MINERVA OIL COMPANY CHURN DRILL HOLE DATA

FIG. 2 COLUMNAR SECTION MINERVA MINE

lying Renault formation, which is of lower Chester age. Stoping is confined to the mineralized Downey's Bluff, which is the upper member of the Renault formation.[20]

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(20) Swann, D. H. and Atherton, Elwood, "Subsurface Correlations of Lower Chester Strata of the Eastern Interior Basin", Illinois Geol. Sur., R.I. No. 135, p. 270, 1948

DETAILED STRATIGRAPHY

MISSISSIPPIAN SYSTEM

Meramec Series

Ste. Genevieve Formation

The Ste. Genevieve formation is composed of three successive members, which from oldest to youngest are: the Fredonia limestone, the Rosiclare sandstone, and the Levias limestone.

Fredonia limestone:

The base of the Fredonia limestone was not encountered in the drill holes studied. The Sub-Rosiclare sandstone is the lowest zone of the Fredonia limestone intersected in churn drill holes. It occurs 60 feet below the top of the Fredonia limestone and is 10 feet thick. The Sub-Rosiclare sandstone has been described by Wagner[21] as being markedly

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(21) Currier, L. W. and Wagner, Jr., O. E., Op. cit. p. 15.

cross-bedded and extremely porous, where exposed, because of the leaching of the calcareous material by weathering. In 1945, Tippie[22] proposed the name of Spar Mountain sandstone to replace the name Sub-Rosiclare sandstone.

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(22) Tippie, F. E., "Rosiclare-Fredonia Contact in and adjacent to Hardin and Pope Counties, Illinois", A.A.P.G., Vol. 29, No. 11, p. 1658, Nov. 1945.

The upper 60 feet of the Fredonia were intersected by a churn drill hole in the vicinity of the Minerva Mine. The limestone is gray, fine-grained to dense, and oolitic.

<u>Rosiclare sandstone</u>:

The Rosiclare sandstone intersected in churn drill holes on the Minerva Oil Company property varies 20 to 40 feet in thickness. Predominantly it is a fine-grained and light gray calcareous sandstone, but the basal portion, immediately overlying the Fredonia limestone, is a dark green to gray shale, 6 to 12 inches thick. To Wagner,[23] the

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(23) Currier, L. W. and Wagner, Jr., O. E., <u>Op</u>. <u>cit</u>. p. 15.

Rosiclare sandstone appeared to be conformable with the underlying Fredonia limestone, but Tippie,[24] who examined

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(24) Tippie, F. E., <u>Op</u>. <u>cit</u>. pp 1654 - 1663.

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diamond drill cores obtained in exploratory drilling for fluorspar in Hardin County, Illinois, and in Kentucky, concluded that an unconformity exists between the Rosiclare sandstone and the underlying Fredonia limestone. He showed that the erosional unconformity is angular, the erosion having been accompanied by pre-Rosiclare warping.

On the basis of similar evidence obtained previously in the Illinois Basin, Workman[25] proposed that the base of the

(25) Workman, L. E., "Subsurface Stratigraphy of Cypress to Fredonia Formations in the Illinois Basin", with discussions by Lynn K. Lee and Robert G. Kurtz, (February 4, 1938, Mimeographed).

Rosiclare sandstone be considered the base of the Chester series.

Swann[26] in 1948 correlated the Rosiclare sandstone

(26) Swann, D. H. and Atherton, E., "Subsurface Correlations of Lower Chester Strata of the Eastern Interior Basin", Illinois State Geological Survey, R. I. No. 135, Fig. 1, p. 270, 1948.

with the Aux Vases sandstone of adjoining regions. If the Aux Vases sandstone is to be considered basal Chester in this region, then the Rosiclare sandstone is basal Chester also.

Levias limestone:

The Levias limestone, youngest member of the Ste. Genevieve formation, is 20 to 60 feet thick and is similar in texture to the Fredonia limestone. It is gray and varies from oolitic through fine-grained to dense.

The name Levias (27) was proposed to replace Weller's (28)

(27) Sutton, A. H. and Weller, J. M., "Lower Chester Correlation in Western Kentucky and Illinois", Jour. Geol., Vol. 40, No. 5, pp 430-439, 1932.

(28) Weller, Stuart, and others, Op. cit. p. 109.

"Lower O'Hara". Weller (29) considered the contact between

(29) Weller, Stuart, and others, Op. cit. pp 114-115.

the "Lower O'Hara" and the underlying Rosiclare sandstone to be conformable. He considered the upper contact between the "Lower O'Hara" and the Chester series to be unconformable. According to Weller, the unconformable surface everywhere "is marked by a distinct basal conglomerate."

Chester Series

Renault Formation

The Renault formation (30) encountered in drill holes on

(30) Weller, Stuart, Kentucky Geol. Sur., Ser. 6, Vol. 4, pp 27-30, 1921.

the Minerva property may be subdivided on a lithologic basis into two members; the basal Shetlerville shale, and the overlying "Renault limestone" or Downey's Bluff member. The thickness of the formation varies from 30 to 70 feet.

Shetlerville shale:

The Shetlerville shale is an interbedded shale and limestone sequence 10 to 35 feet thick. The shale is dark green to gray thin-bedded, and in part, fissile. The interbedded limestone is dense to fine-grained, and in part, crinoidal. The layers of limestone and shale grade laterally into one another. The thickest individual shale bed measured in the Minerva Mine was 8 feet thick. The limestone layers are from 2 inches to 4 feet thick.

In 1943, Tippie[31] zoned the Renault formation on the

(31) Tippie, F. E., "Insoluble Residues of the Levias and Renault Formations in Hardin County, Illinois", Ill. State Geol. Sur. Circular No. 102, pp 155-157, 1944.

basis of insoluble residues obtained from diamond drill cores and from outcrop samples. The zones were designated A, B, C, D, and E, starting at the base of the formation. In the Minerva Mine, the lower predominantly shale portion of the Renault formation was considered to comprise the Shetlerville shale member.

Downey's Bluff, or "Renault limestone":

The upper member of the Renault formation is the so-called "Renault limestone" or Downey's Bluff. 20 to 35 feet of this limestone were cut by the drill holes. The limestone is gray to brown, thick-bedded, and varies texturally from dense to medium-grained. Oolitic and crinoidal beds are present. The "Renault limestone" has been named the Downey's Bluff member (32) by Tippie from the type locality

(32) Atherton, E., "Some Chester Outcrop and Subsurface Sections in Southeastern Illinois", Illinois Acad. Sci. Trans., Vol. 40, p. 129, Illinois State Geol. Sur. Circ. 144.

Downey's Bluff along the Ohio River bluff at Rosiclare. In this report the name "Renault limestone" is retained because it is the name in common usage in the Illinois fluorspar field.

In the Minerva Mine workings, the upper parts of the "Renault limestone" are porous. This porosity may have been induced by subaerial weathering or by solution by circulating ground water, or by both.

The "Renault limestone" is overlain unconformably (33)(34)

(33) Weller, Stuart, and others, *Op. cit.* p. 145.

(34) Tippie, F. E., *Op. cit.* pp 155-157.

by the Bethel sandstone. Tippie found that the Bethel sandstone, in the Illinois fluorspar area, rests in places directly on Zone C and D of the Renault formation. The absence of the overlying zones indicates an unconformity between the Renault formation and the overlying Bethel sandstone.

Bethel Sandstone

Weller[35] found that the Bethel sandstone varies in thickness from 45 to 100 feet. It is composed of subrounded well-sorted quartz sand and a very little feldspar and zircon. The sandstone is compact and is cemented by quartz. It is tan to nearly white and when fresh, is cross-bedded and ripple-marked. The Bethel sandstone is separated from the Renault limestone by a shale layer which is usually 6 to 12 inches thick, although locally it may be 2 to 3 feet thick. The Bethel sandstone is the youngest formation exposed in the stopes of the Minerva Mine.

In the vicinity of this mine, it is overlain directly by the Cypress sandstone. The Paint Creek shale, which normally separates these two formations, is missing.

The following described formations successively overlie the Bethel sandstone and are described only briefly because they are not directly related to the fluorspar deposits.

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(35) Weller, Stuart, and others, Op. cit. p. 164.

Cypress Sandstone

The combined thickness of the Cypress sandstone and Bethel sandstone, as obtained from churn drill data, ranges from 170 to 200 feet. The Cypress sandstone is similar to the Bethel sandstone in character.

Golconda Formation

The Golconda formation is 160 to 180 feet thick in the vicinity of the Minerva Mine. It is composed of a succession of shale and limestone beds, but is predominantly limestone.

Hardinsburg Sandstone

Churn drill data indicates that the Hardinsburg sandstone ranges from 70 to 90 feet in thickness. The Hardinsburg sandstone contains shale beds and shaly partings; therefore it is not as massive as the underlying Cypress and Bethel sandstones.

Glen Dean Limestone

The Glen Dean limestone varies in thickness from 60 to 75 feet. The formation is comprised of alternating shale and limestone beds.

Tar Springs Sandstone

The Tar Springs sandstone is 60 feet thick. It is tan to nearly white. Interbedded shale is present. The Tar Springs sandstone forms the bedrock over part of the area in the vicinity of the Minerva Mine.

Menard Limestone

The Menard limestone also underlies the surface in the vicinity of the Minerva Mine. A maximum thickness of 20 feet was encountered in the drill holes. Weller[36] determined its regional thickness as 80 to 120 feet. The Menard is predominantly comprised of limestone beds, although some shaly partings are present. It is overlain unconformably to the northeast of the Minerva Mine by the Caseyville conglomerate of Pennsylvanian age.

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(36) Weller, Stuart, and others, Op. cit. p. 206.

GEOLOGIC STRUCTURE

Folds

The Cave in Rock district is on the northeast limb of a broad domal structure which trends northwesterly, through the Illinois-Kentucky fluorspar area. The sedimentary rocks of this region strike N.70°W. to N.80°W. and dip homoclinally to the northeast. At the southern end of the Cave in Rock district, near the crest of the fold, the average dip is 2°. The dip steepens gradually to the northeast on the flanks of the fold. In the vicinity of the Minerva Mine, the average dip is from 3° to 5°.

Local variations in strike and dip were noted in the Minerva Mine workings. These variations are related to the fracture system present. Minor anticlines and synclines within fracture zones trend parallel to the strike of the fractures.

Drag of beds along faults also was noted in the mine workings. The steep dips are due to drag restricted to the immediate vicinity of the minor faults. The steepest dip observed was 45°. The strikes of the dragged beds parallel the fractures to which they are related.

Fractures

A large number of normal faults are associated with the broad domal structure which characterizes the Illinois-Kentucky fluorspar area. These faults have vertical displacements up to 1500 feet.[37]

(37) Weller, Stuart, and others, <u>Op</u>. <u>cit</u>. p. 56.

In Hardin County, the predominant faults strike N.25°E. to N.55°E., and are steeply dipping, or vertical. Both northwesterly and southeasterly dipping faults are present.

The Cave in Rock district is bounded on the west by the Peters Creek fault zone, which strikes N.50°E. and has an overall displacement of 1000 feet downthrown on the northwest side.[38] None of the major normal faults which characterize the Illinois-Kentucky fluorspar area occurs within the Cave in Rock district itself.

(38) Weller, Stuart, and others, <u>Op</u>. <u>cit</u>. p. 69.

In the vicinity of the Minerva Mine, exposures of fractures can be found in creek bottoms. The fracture pattern developed consists of three sets of nearly vertical fractures. One set strikes N.50°E. to N.55°E. paralleling the trend of the prominent normal faults. The second set strikes N.55°W. to N.60°W., and the third set strikes east-west.

This same fracture system is present in the underground workings of the Minerva Mine, as shown in Figure 3. The few normal faults present strike N.50°E. to N.55°E. The maximum measured vertical displacement along one of these faults is

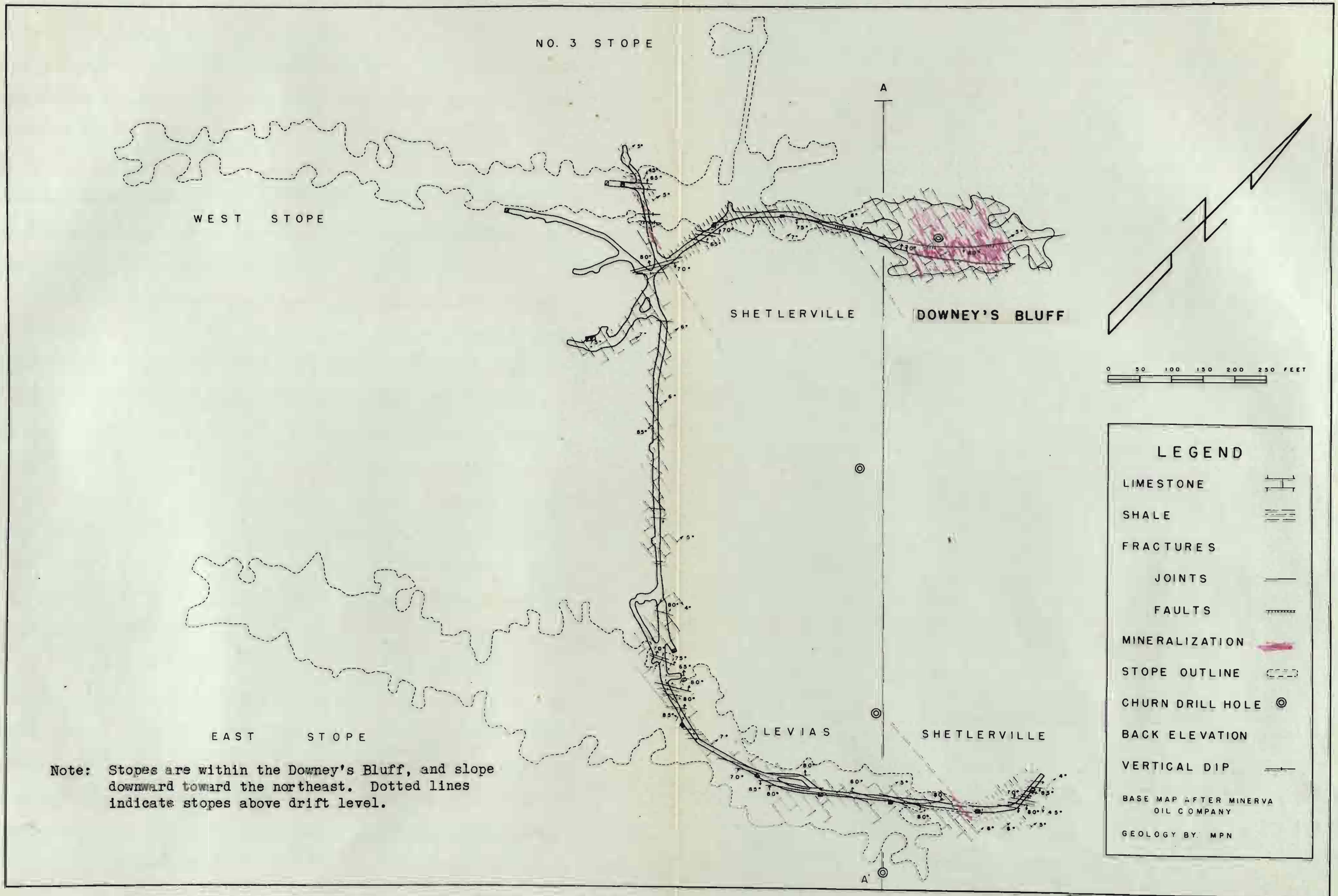
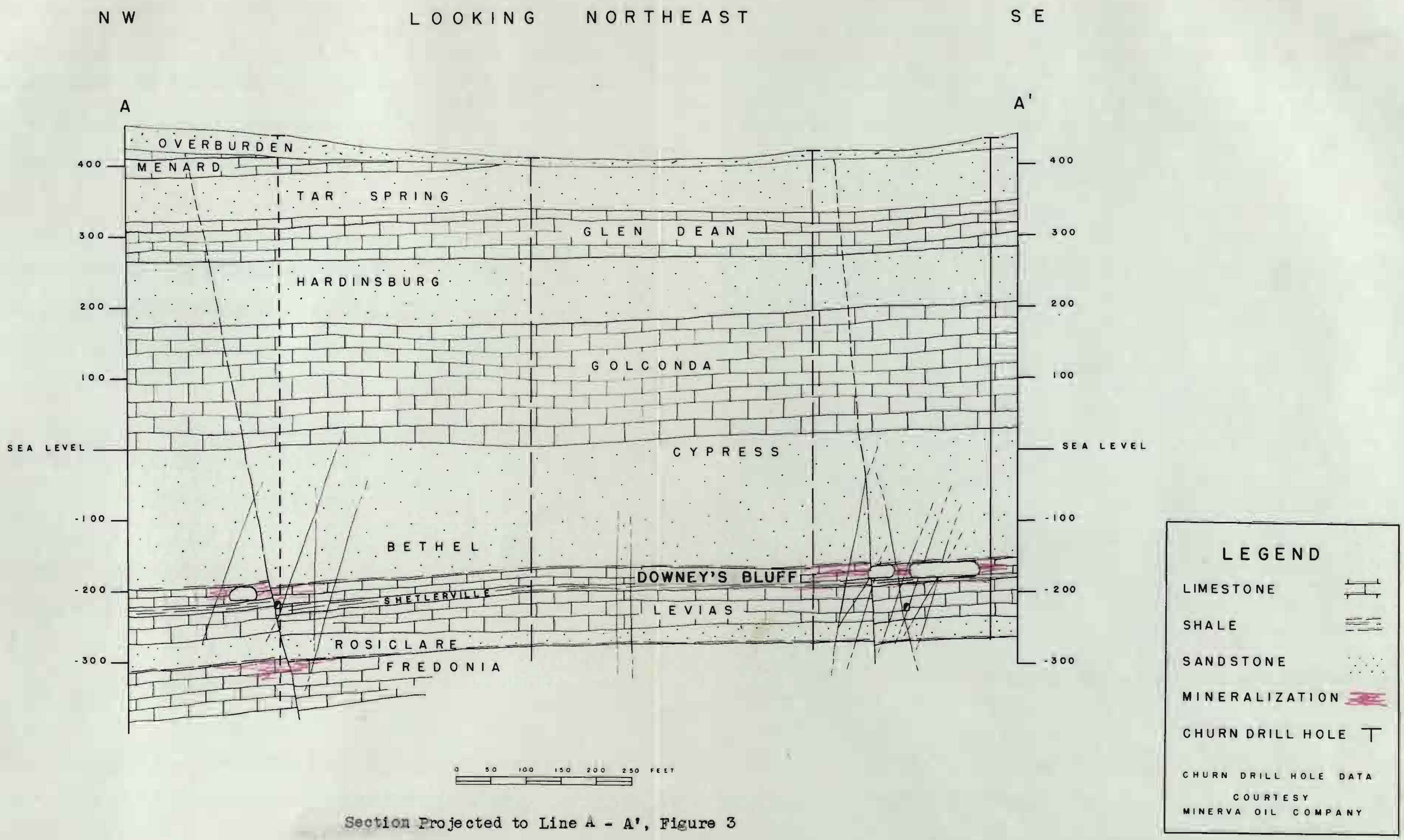


FIGURE 3, GEOLOGIC MAP OF DRIFT LEVEL, MINERVA MINE NO. 1

3 feet. The majority of the fractures of this set are joints. The fractures which trend N.55°W. to N.60°W. and those which trend east-west are also joints, since no perceptible displacement is present along them. In the mine workings the fractures are filled with calcite and with calcite and fluorite, forming veinlets which range in width from 1/16 of an inch to 4 inches. The majority of the veinlets are from 1/2 to 1 inch wide.

The character of the fractures is controlled by the structural competency of the formations through which they pass. This control is more noticeable with the smaller joints. The larger fractures pass through the limestone, shale, and sandstone sequence without deviation in their course, while the smaller fractures are most closely spaced in the shales and are widely spaced in the sandstones. The spacing of the fractures in the limestone is intermediate. Some of the joints within the shales are discontinuous. Joints passing from limestone into shale may end within the shale bed. Bedding plane slipping within the shale beds has displaced some of the fractures. In the massive limestone, the joints are continuous and consistent in their dip. In the bedded limestone, however, the smaller joints are steplike in character. A vertical joint will change direction of dip, follow a bedding plane for a distance of 1 to 24 inches and then continue vertically. The step-like pattern is repeated by the smaller joints which traverse the bedded limestone.

The N.50°E. to N.55°E. set of fractures are predominant in the Cave in Rock district and in the workings of the Minerva Mine. Within the mine, they occur in zones which coincide in position with the mineralized zones, as shown by the relation of the stopes to the fractures on the mine map Figure 3, and on the Geologic Cross Section, Figure 4. The east stope fracture zone, 200 feet wide, consists of a series of closely spaced N.50°E. trending fractures. The drift level mine workings between the east and west stopes, a distance of 600 feet, are traversed by occasional minor fractures. The west stope fracture zone, 150 feet wide, contains a closely spaced fracture pattern similar to that of the east stope. Two hundred feet northwest of the west stope, No. 3 stope also occurs in a similar fracture zone. The fractures were developed both prior to and contemporaneous with mineralization. Pre-mineral fractures are filled with vein material. Inter-mineral fracturing is indicated by vein filling or "healing" of fractured calcite veins.



Section Projected to Line A - A', Figure 3

FIGURE 4, GEOLOGIC VERTICAL SECTION, MINERVA MINE NO. I

MINERALIZATION

The minerals associated with the fluorspar of the Minerva Mine include most of those previously described from other mines in Hardin County, Illinois,[39] and in

(39) Weller, Stuart, and others, Op. cit. Part V, pp 252-254
Bastin, E. S., Op. cit. pp 55-64.
Currier, L. W. and Wagner, Jr., O.E., Op. cit. pp 30-33

addition, two minerals, witherite and strontianite, which have not been described previously from the area. Witherite and strontianite were identified in specimens from the Minerva Mine No. 1. Witherite also was found in the West Green Mine of the Ozark Mahoning Company. Marcasite,[40]

(40) Bastin, E. S., Op. cit. p. 63.
Currier, L. W. and Wagner, Jr., O.E., Op. cit. p. 39.

which has been described previously in specimens from the bedding replacement deposits was not observed by the present writer.

Description of Minerals

Calcite:

Calcite deposited from mineralizing solutions is present in the ore bodies and as veinlets filling fractures. It is colorless, white, yellowish, or gray, and is fine-grained to coarse-grained. The vein calcite has poorly developed crystal faces. The calcite deposited in open spaces occurs as singly or doubly terminated scalenohedrons which are modified by rhombohedral faces. Coarsely crystalline gray calcite has filled cavities in the ore. These rhombohedral calcite masses are from 6 to 24 inches long. Crusts of white fine-grained, powdery calcite coat the walls of open channels.

Fluorite:

Fluorite is the most abundant useful mineral in the Minerva Mine. Its grain size varies from microscopic to crystals which measure 4 inches on edge. The fluorite is poorly crystallized where it occurs as disseminated grains in the limestone, and well-crystallized where it has been deposited in open cavities. The most common form is the cube. Octahedral faces rarely modify the cube form.

The fluorite is white, yellowish buff, greenish blue, sky blue, lavender, and purple. Individual crystals commonly show color zoning, which gives rise to ghost crystals. The color boundaries are sharp, although a gradation in intensity of a color may occur within a particular zone.

Inclusions are present in the fluorite. When abundant, the inclusions are symmetrically arranged according to a cubic pattern because they were deposited on exposed cube crystal faces. Continued growth of the fluorite crystals enclosed the foreign matter. The inclusions recognized in the fluorite crystals from the Minerva Mine consisted of chalcopyrite. Hydrocarbon inclusions have been reported [41]

(41) Weller, Stuart, and others, Op. cit. p. 254.
Bastin, E. S., Op. cit. pp 37 and 64.
Currier, L. W. and Wagner, Jr., O. E., Op. cit. p. 31.

from other mines in the fluorspar district.

Barite:

The barite in the Minerva Mine is granular, powdery, acicular, or tabular. It is white, yellowish, or colorless. The tabular crystals have a well-developed equidimensional basal pinacoid, a narrow prism, and small macro- and brachydomes. The barite was deposited primarily in open channels and in adjoining cavities.

Witherite:

The witherite occurs as pseudo-hexagonal twinned crystals and aggregates. The pseudo-hexagonal twins are stubby and columnar. Nearly flat dipyramidal faces terminate the columns. The witherite is white to buff, waxy to vitreous, and occasionally zoned. Some pseudo-hexagonal crystals have a white waxy core surrounded by a buff vitreous exterior. Inclusions are present in some specimens along the zone boundary.

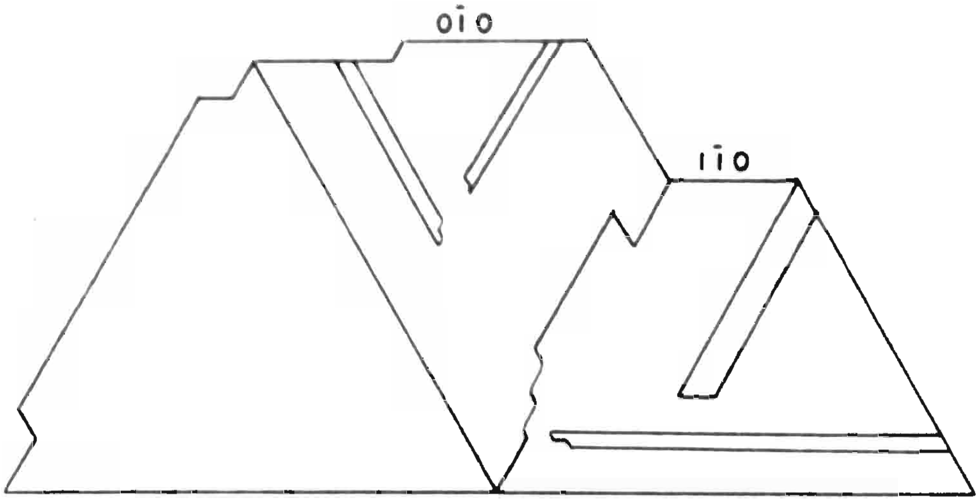
The small witherite twins are multiple cyclic twins with the unit prism acting as the twinning plane. In the larger twins, a complex arrangement of individuals occurs. Cyclic twinning still is developed with the unit prism as the twinning plane, but polysynthetic twinning according to the same law also is present, as shown in Figure 5. In addition, the twins exhibit an aggregate texture which is best observed in thin sections under crossed nicols. Frequently this aggregation gives rise to a radial or even flamboyant effect.

Under an ultraviolet lamp, the witherite strongly fluoresces white. A weak yellow phosphorescence is also exhibited. The x-ray diffraction pattern obtained from witherite from the Minerva Mine was identical with that obtained from English witherite.

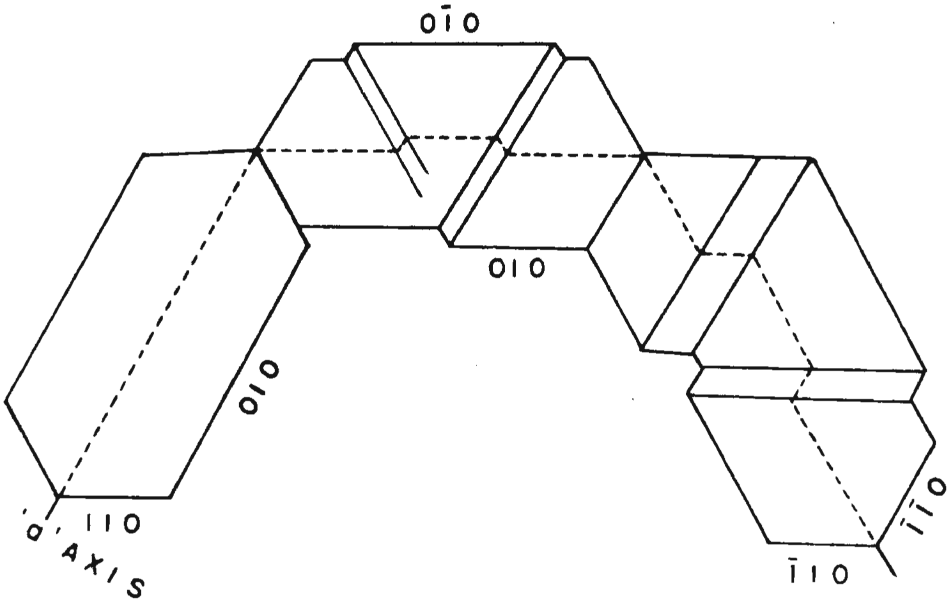
Witherite was deposited in open cavities and channels exclusively. At the West Green Mine, the witherite is corroded, having undergone partial zonal solution by groundwater.

Strontianite:

Strontianite was identified in specimens from the Minerva Mine by the writer. It is pink to brown, and bladed to acicular. The brown color is due to petroleum inclusions in the acicular aggregates of the mineral. Physical, optical, and chemical tests were supplemented by an x-ray diffraction pattern in the identification of the strontianite.



GENERALIZED CAMERA LUCIDA SKETCH OF ONE HALF OF A SIMPLE PSEUDO-HEXAGONAL TWIN AS SEEN IN THIN SECTION ORIENTED PERPENDICULAR TO THE "C" AXIS UNDER CROSSED NICOLS. (6X)



SCHEMATIC DIAGRAM OF THE WITHERITE TWIN. TWIN PLANE (110). DOTTED LINE INDICATES DIRECTION OF THE "A" AXIS.

FIG. 5, SKETCH AND DIAGRAM OF SIMPLE PSEUDO-HEXAGONAL WITHERITE TWIN.

Although strontianite has not been described previously from Illinois fluorspar mines, celestite (42) has been de-

(42) Hardin, G. C.Jr., and Thurston, W. R., "Celestite From Livingston County, Kentucky", Am. Min. Vol. 30, No. 9, and 10, p. 639.

scribed from the Jameson prospect, eight miles northwest of Salem, Livingston County, Kentucky.

Quartz:

Colorless quartz crystals are present in the Minerva Mine. The quartz crystals vary from 1/8 to 1/4 of an inch in length, and exhibit horizontally striated hexagonal prism faces and rhombohedral faces. The quartz has formed on other minerals.

Sphalerite:

Sphalerite, honey yellow or dark brown, is widely distributed. The grains range from microscopic dimensions to crystals which are 1/2 to 3/4 inches across.

Chalcopyrite:

Chalcopyrite is not abundant in the Minerva Mine, but it is widely distributed. The simple tetragonal disphenoid (111) is the crystal form developed. The chalcopyrite occurs as inclusions within the fluorite, and is also attached to crystal faces of the fluorite and other minerals.

Galena:

Galena is not common in the workings of the Minerva Mine. Crystal aggregates were observed. The crystals were cubes modified by octahedrons.

Petroleum:

Petroleum seeps occur in the mine workings along fractures and bedding planes. The sandstones and limestones of the Chester series yield oil commercially in southern Illinois.

Paragenesis of the Fluorspar Deposit

The sequence of mineral deposition in the Minerva Mine is similar to that noted by Bastin.[43]

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(43) Bastin, E. S., *Op. cit.* pp 55-63.

Fluorite:

The first mineral to be deposited was fluorite, and this mineral continued to be deposited throughout the major portion of the period of mineralization. Leached cusp-like surfaces of fluorite were seen along open bedding plane channels, indicating a period of fluorite solution.

Small crystals of fluorite 1/16 to 1/8 of an inch across are found deposited on witherite surfaces, indicating that at least a minor amount of fluorite was deposited after the crystallization of the witherite.

Sphalerite:

Cross-cutting relationships were not noted between fluorite and sphalerite. In thin section, fluorite crystals euhedral to sphalerite or enclosing sphalerite were observed. These observations indicate that sphalerite crystallized after the first fluorite had been deposited and ceased before the deposition of fluorite was complete.

Chalcopyrite:

Chalcopyrite occurs as zonally distributed inclusions in fluorite. The chalcopyrite was deposited on the cube faces of the fluorite, which with continued growth enclosed the chalcopyrite. Chalcopyrite also occurs as disphenoid crystals on witherite. This indicates that chalcopyrite continued to be deposited after the formation of the witherite. Chalcopyrite deposition began after fluorite, and continued throughout the period of mineralization.

Galena:

The limited occurrence of galena in the Minerva Mine prevented a precise determination of its age. It occurs as crystals on fluorite and is later than the fluorite. In the Crystal Mine, galena crystals were found coated with a thin film of chalcopyrite, indicating that it is older than the chalcopyrite.

Calcite:

Calcite veinlets cross-cut fluorite. This indicates fracturing of the fluorite and subsequent sealing of the fractures by calcite. These calcite veinlets occur as a netlike box-work in open channels along which fluorite has undergone solution. Small calcite crystals found on witherite indicate that the deposition of calcite continued after the witherite was formed. Crusts of powdery calcite on other minerals were noted and may have been deposited from ground water after cessation of mineralization.

Barite:

Some of the barite is partly replaced by witherite. Acicular aggregates of barite have been infiltrated by strontianite, which partly replaces the barite. The distribution of barite is related to the open channels and cavities. No.barite was noted on leached remnants of fluorite, however, indicating that it was deposited prior to the solution of fluorite.

Witherite:

Partly replaced barite rods are enclosed in the pseudo-hexagonal witherite twins. Witherite was also found in cavities of acicular aggregates of barite. The witherite is principally related to open bedding plane channels and cavities. It is found crystallized on or along calcite veinlets, which have remained as a box-work, following the solution of fluorite through which these veinlets originally cut. Witherite therefore was deposited after the period of fluorite solution.

Strontianite:

Strontianite fills open spaces in masses of loosely aggregated barite needles. Strontianite has partly replaced barite needles, indicating that it was deposited after barite.

Quartz:

A small amount of quartz is present in the Minerva Mine. Quartz crystals were deposited on crystal faces of fluorite, calcite, barite, and witherite, indicating that its deposition outlasted that of the other minerals. Powdery crusts of calcite, however, do coat the quartz crystals.

NATURE OF THE FLUORSPAR DEPOSIT

Ore Textures

The ore in the Minerva Mine can be separated texturally into three classes which are genetically related to the physical-chemical conditions prevailing during the period of mineralization and to the physical characteristics of the host rock. The physical-chemical conditions involve primarily temperature, pressure, absolute and relative concentrations of ions and molecules in solution, and changes in these factors during the period of mineralization.

Banded, or "coon-tail" ore:

The banded ore is composed of alternating layers of light-colored and dark-colored fluorite, or alternating layers of pure fluorite and impure fluorite. Each layer or band is from 1/2 to 2 inches thick. These layers extend parallel to the bedding of the host rock and according to Currier,(44) "reflect and preserve the original bedding,

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(44) Currier, L. W., Econ. Geol., Op. cit. p. 378, 1937.

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cross-bedding, and to some extent, the textures of the host limestone".

Bastin(45) has attributed the banding to deposition of fluorite by rhythmic precipitation during replacement of the

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(45) Bastin, E. S., Op. cit. p. 53.

limestone by diffusing mineralizing solutions. The banding was found not to be parallel to the bedding in all cases. Where departures from parallelism were marked, the orientation of the banding was related to small fractures cutting across the bedding planes.

The banded or "coon-tail" ore is developed to a limited extent at the Minerva Mine No. 1. The banding reflects the structure of the replaced limestone, but replacement of carbonate ions by fluoride ions alone cannot account for the structure. Such a reaction would involve a volume change of about 33 percent, for which there is no evidence. Apparently the mineralizing solutions carried calcium fluoride and a volume rather than molecular replacement took place. This also is evidenced by the development of highly crystalline and rather pure fluorite bands between those which exhibit evidence of replacement.

Coarse granular, or massive ore:

The coarse granular ore shows a crude irregular coarse banding in places. The crude bands are from 1 to 4 inches thick. The crystals developed are from 1/2 to 6 inches across. Coarse granular ore fills former cavities and channels. The coarse fluorite includes limestone fragments. The fragments of unreplaced limestone are either parallel to the original bedding of the limestone or assume inclined positions, indicating that they slumped into cavities formed during the period of mineralization.

The growth of comparatively large crystals of fluorite, the indistinct or crude preservation of bedding features, the presence of slump structures and open channels and cavities, indicate that although deposition of fluorite was initiated by replacement of the limestone, the solution of the limestone progressed independently, and the openings formed were filled or partly filled by fluorite deposited from solutions not as concentrated in calcium and fluorine, as were those which developed the banded ore.

Disseminated ore:

The majority of the ore in the Minerva Mine is characterized by the presence of fine granular fluorite distributed through the host rock. A linear arrangement of the fluorite grains parallel to bedding of the limestone is visible. Development of disseminated texture is the result of replacement of calcite by fluorite.

Shape of the Ore Bodies

The ore bodies of the Minerva Mine are tabular in form and are elongated in a N.50°E. to N.55°E. direction parallel to the strike of the predominant fractures. The ore bodies being mined lie within the "Renault limestone" Downey's Bluff member of the Renault formation. Their upper contact coincides with the basal shale of the overlying Bethel sandstone. Although some disseminated mineralization does occur in the Bethel sandstone, it is not of commercial importance.

The widths of the ore bodies are limited by decreased intensity of mineralization at the outward limits of the fracture zones and range from 50 to 300 feet. The bottoms of the ore bodies are irregular, and not sharply defined. The ore bodies range from 3 to 20 feet in thickness. Their average thickness is 9 feet. The minimum fluorspar and zinc content upon which the limits of the ore bodies are based were not available to the writer.

Relation to Formations

The most important fluorspar-bearing rock in the Cave in Rock district has been the Fredonia limestone of the Ste. Genevieve formation. Several mineralized horizons occur within the Fredonia limestone. The most important and extensive ore bodies lie directly beneath the thin shale found at the base of the overlying Rosiclare sandstone member. A second mineralized horizon has been found directly beneath the Sub-Rosiclare sandstone, which is within the Fredonia limestone, and about 60 feet below the top of this member. Other mineralized horizons of more limited extent also have been found within the Fredonia limestone. These occur directly beneath dense lenses or layers of Fredonia limestone.

Exploratory churn drilling in the Minerva Mine area disclosed mineralization at two new horizons, the "Renault limestone" or Downey's Bluff, and the Levias limestone. Fluorspar had not been produced previously from these stratigraphic zones. Of these, the productive and most intensively mineralized horizon at the Minerva Mine is within the "Renault limestone" Downey's Bluff member of the Renault formation. The ore in this horizon lies directly beneath the thin basal shale of the overlying Bethel sandstone. The upper part of the Fredonia limestone, directly beneath the basal shale of the Rosiclare sandstone also is mineralized, but not worked at present. The mineral occurrence in the Fredonia limestone and in the "Renault limestone" are quite similar, in that both occur beneath a thin shale, which is a basal phase over an overlying sandstone.

Relation to Fractures

The fractures in the Minerva Mine drift level workings can be divided into three sets. One set strikes N.50°E. to N.55°E., the second set strikes N.55°W. to N.60°W., and the third set strikes east-west. All are steeply dipping or vertical. The most prominent fracture set trends N.50°E. to N.55°E. The fractures of this set are grouped in well-defined zones. The mineralized areas occupy positions within the fracture zones trending N.50°E. to N.55°E. In other mines in the Cave in Rock district, the major mineralized trends extend laterally parallel to these same fractures. In addition, ore bodies have been found which have a N.55°W. to N.60°W. trend and are parallel to fractures striking in this direction. Replacement of limestone layers by fluorite adjacent to the fractures is absent except at mineralized horizons.

Relation to Folds

Minor flexures and drag folds are associated with fractures in the Minerva Mine. No marked relationship was noted between these flexures and the intensity of mineralization. In other mines in the Cave in Rock district, Currier[47] has found that mineralization is most intense on

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(47) Currier, L. W. and Wagner, Jr., O. E., Op. cit. p. 41.

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flanks of sharp folds, and principally in synclinal troughs. Where ore has been found on anticlinal crests, the folds are sharper than where they are not mineralized.

ORIGIN OF ORES AND FACTORS CONTROLLING MINERAL LOCALIZATION

The origin of the fluorspar ores of the Illinois-Kentucky fluorspar district has been attributed to deposition of minerals from ascending hydrothermal solutions derived from an underlying differentiated magma. The presence of such a differentiated magma is indicated by the acidic igneous breccia plugs and lamprophyric dikes which occur in the area. That the mineralizing solutions were ascending from below is suggested by the position of mineralized horizons directly beneath impervious cap rocks. The ascending mineralizing solutions travelled along available channels, which were the fractures occurring in this district.

The elongation of ore bodies parallel to the N.50°E. to N.55°E. fracture set indicates they were the more favorable channels of ascent for solutions. Near Rosiclare, Hardin County, the larger faults offered channel-ways of unrestricted movement to migrating solutions. Here are formed the vein deposits, with no related bedding replacement deposits.

In the Cave in Rock area, large fractures have not been encountered. Relief of stresses by fracturing was accomplished in zones of minor normal faults and joints, rather than along a definite plane of major movement. These minor fractures offered restricted channel-ways to ascending mineralizing solutions. Lateral migration of the mineralizing solutions to form the bedding replacement deposits has previously been attributed to the damming of the solutions by a cap rock, thereby causing them to spread laterally.[48]

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(48) Currier, L. W. and Wagner, Jr., O. E., Op. cit. p. 49.

Data obtained in the Minerva Mine workings and from churn drill holes indicate that the damming influence of a cap rock was of secondary importance in mineral localization.

Ascending solutions may be caused to migrate laterally 1) when their ascent is impeded by a dense cap rock at which a fracture is cut off or narrowed, or 2) when the solutions encounter a more permeable channel or medium than that through which they were migrating, or 3) when a combination of the first two factors takes place.

Evidence obtained in the Minerva Mine indicates that the permeable nature of the "Renault limestone" or Downey's Bluff member caused solutions to migrate laterally, although it is overlain by a shale which is only 6 to 12 inches thick. "Renault limestone" specimens obtained from the Minerva Mine within 4 feet of its contact with the overlying Bethel sandstone were porous. It is supposed that this porosity was induced by subaerial weathering, and by solution due to percolating ground waters obtained from the overlying sandstone.

The similar stratigraphic position of the Fredonia limestone, which also is strongly mineralized, with respect to the overlying Rosiclare sandstone gives credence to this postulate.

The second mineralized horizon in the Minerva Mine is within the Levias limestone. Levias mineralization is limited in extent and weak. However, this limestone is lithologically similar to the Fredonia limestone and is overlain by the Shetlerville shale, which contains a shale bed 8 feet thick in the Minerva Mine. If the effect of an impervious cap rock were the primary cause for lateral migration of solutions, the Levias limestone should be at least as strongly mineralized as the Fredonia, with which it is lithologically similar. Therefore, it is concluded that permeability of the "Renault limestone" and the Fredonia limestone was of primary importance in mineral localization, and the presence of an impervious cap rock was of secondary importance.

CHEMISTRY OF THE FLUORSPAR DEPOSIT

Various theories have been proposed to describe the chemistry of fluorspar deposition. Weller[49] proposed the

(49) Weller, Stuart, and others, *Op. cit.* p. 279.

following reactions assuming that fluorine and silica were solutes, and that fluorine was obtained from an underlying differentiated magma.

1) $2F_2 + 2H_2O \dashrightarrow 4HF + O_2$

2) $SiO_2 + 4HF \dashrightarrow SiF_4 + 2H_2O$

3) $SiF_4 + \underline{2CaCO_3} \dashrightarrow \underline{SiO_2} + \underline{2CaF_2} + 2CO_2$

4) $2HF + \underline{CaCO_3} \dashrightarrow \underline{CaF_2} + H_2O + CO_2$

The presence of elemental fluorine indicated in reaction 1 as a magmatic differentiate, or "fugitive constituent"[50] is questioned. Fluorine is a component of certain

(50) Shand, S. James, "Eruptive Rocks", Second Edition, John Wiley and Sons, Inc., New York, P. 34, 1943.

igneous and related minerals, indicating that it was present in the magma in the ionic state. Quartz, although present in the fluorspar deposits, does not exist in quantities required if reactions 2 and 3 were largely responsible for fluorspar deposition. It is probable that fluorine in the ionic state was accompanied by sodium, potassium, calcium, or other ions, as well as by hydrogen ions. It is assumed that the mineralizing solutions had a low hydrogen ion concentration, thereby limiting the reaction of fluoride ions with silicates to form H_2SiF_6.

The following generalized equilibrium reactions are presented to illustrate the nature of fluorite deposition:

4) $2HF + \underline{CaCO_3} \rightleftharpoons \underline{CaF_2} + H_2CO_3$

5) $H_2CO_3 + \underline{CaCO_3} \rightleftharpoons Ca(HCO_3)_2$

6) $Ca^{++} + 2F^{-} \rightleftharpoons \underline{CaF_2}$

Reaction 4 involves the stoichiometric replacement of calcite by fluorite. The production of carbonic acid by this reaction will result in the solution of limestone as indicated in reaction 5 with the development of the soluble calcium bicarbonate. The increased concentration of calcium ions in solution will force the deposition of further fluorite as indicated in reaction 6. The formation of the bicarbonate ion will also decrease the concentration of CO_2 in solution and so allow reaction 4 to progress further to the right than indicated.

A decrease in the degree of saturation or concentration of CO_2 in solution which would favor reaction 4 can be obtained either by 1) lowering the temperature and thereby increasing the solubility of CO_2, or 2) by encountering ground waters not themselves saturated in CO_2, in which the excess of CO_2 in the mineralizing solutions may be dissolved, or 3) by decreasing pressure, allowing for the escape of accumulated CO_2, or 4) by the formation of the bicarbonate ion.

Decreased temperature will also favor deposition of CaF_2 according to reaction 6 because its solubility decreases with lowered temperatures, whereas the solubility of calcium carbonate in carbonic acid solution increases with decreasing temperature, as indicated in reaction 5. Although lowered pressures will favor deposition of fluorite, according to reaction 4, deposition of calcite will also occur, due to the reversal of reaction 5.

It is assumed that the mineralizing solutions ascending along fractures were in a state of equilibrium because the limestone wall rock adjacent to the fractures, except at mineralized horizons, is not replaced by fluorite, nor has the limestone undergone solution. Upon reaching horizons at which the solutions were allowed or forced to migrate laterally, a temperature drop occurred favoring deposition of fluorite. This condition was present at the upper contact of the Fredonia, the Levias, and the Downey's Bluff or "Renault limestone". At the Fredonia and Downey's Bluff horizons, ground water present in the upper permeable horizons and in the overlying sandstones aided deposition of fluorite. The effect of two factors, 1) lowering temperature and therefore favoring fluorite deposition, and 2) encountering ground waters which would decrease the degree of saturation of CO_2 in the mineralizing solutions, help to account for the relative intensity of mineralization encountered in the Downey's Bluff and the Fredonia, as compared to the more weakly mineralized Levias.

CONCLUSIONS

The geology and mineralogy of the Minerva Mine No. 1 was the outgrowth of a study first undertaken to describe the nature and occurrence of witherite, identified by Dr. O. R. Grawe in a specimen from this mine. Witherite had not been described previously from the Illinois-Kentucky fluorspar area. Strontianite, which had not been described previously from this area was identified by the present writer. Both minerals were formed late in the mineralization process, and replaced barite, as well as being deposited from solution on other minerals. The paragenetic sequence of the non-sulphide minerals appears to be: fluorite, calcite, barite, strontianite, and witherite. Paragenetic relationships of the sulphide minerals were not definitely established. The sphalerite, chalcopyrite, and galena were formed after the first deposition of fluorite. The witherite was deposited after a period during which fluorite was dissolved in open channels and cavities. Minor deposition of fluorite and calcite occurred following the formation of the witherite. In the West Green Mine workings, which are nearer the surface than the Minerva Mine workings, the witherite exhibits the effect of late zonal solution by ground water.

The fluorspar deposits of the Minerva Mine No. 1 and other bedding replacement deposits in the Cave in Rock district are definitely related to the fracture system seen on the surface and in the mine workings. This fracture system includes three sets of fractures, the most important of which strikes N.50°E. to N.55°E. The second set in importance strikes N.55°W. to N.60°W. and the third set strikes east-west. These fractures are steeply dipping or vertical and consist of minor normal faults and joints. Mineralizing solutions ascended along these fractures and spread laterally at favorable horizons to form the bedding replacement fluorspar deposits. The deposits are tabular, are elongated principally parallel to the N.50°E. to N.55°E. striking fractures, and are confined laterally within zones of closely spaced fractures. The fluorspar deposits therefore are closely related to the intersections of definite zones of fractures with definite stratigraphic horizons. At the Minerva Mine these horizons are the Fredonia limestone, the Levias limestone, and the Downey's Bluff or "Renault limestone".

It has been stated previously that the occurrence of an impervious cap rock was responsible for lateral migration of the mineralizing solutions beneath the cap rock. In the Minerva Mine, the Downey's Bluff, "Renault limestone", is most extensively and intensively mineralized. It is overlain by the Bethel sandstone, at the base of which occurs a 6 to 12 inch shale. The Levias limestone, which is most weakly and sporadically mineralized in the Minerva Mine, is overlain by the Shetlerville shale, which is an interbedded shale and limestone sequence. The thickest shale bed is

8 feet thick. The Fredonia limestone, which in the Cave in Rock district is the major mineralized horizon, is overlain by the Rosiclare sandstone, at the base of which a 6 to 12 inch shale occurs.

The stratigraphic distribution of the fluorspar deposits indicates that the permeability of the mineralized horizons was more important than the nature and thickness of the overlying cap rock. Original permeability was probably increased by subaerial weathering and by solution of the limestone by ground water obtained from the overlying sandstones. Therefore, the sandstones above the Downey's Bluff or "Renault limestone" and the Fredonia limestone are indirectly responsible for the lateral migration of mineralizing solutions and more important than the shales, which acted as cap rocks, in mineral localization.

Three types of ore textures occur in the bedding replacement deposits: banded or "coon-tail" ore, granular or massive ore, and disseminated ore. These types are related to the physical characteristics of the sediments in which they developed, and to the physical-chemical conditions prevailing at the time of mineral deposition. The development of the banded or "coon-tail" ore required volume replacement. Stoichiometric replacement of calcite by fluorite results in a 33 percent volume reduction. Openings so formed were immediately filled by deposition of fluorite from solution. The formation of the coarse granular, or massive ore involved not only stoichiometric replacement of the limestone, but actual solution of the limestone. This was accompanied by the deposition of fluorite which did not keep pace with the rate at which openings were formed. Slump structures indicate the presence of large open cavities during the formation of the coarse granular or massive ore. The disseminated ore was developed by the incomplete and minor replacement of limestone by fluorite along bedding planes.

Mineral localization at favorable stratigraphic horizons was also controlled by physical-chemical conditions existing at these horizons. The limestone wall rock adjacent to the fractures along which the mineralizing solutions ascended are not replaced by fluorite or dissolved except at the mineralized horizons. Therefore, the ascending solutions were in equilibrium until they were forced or allowed to migrate laterally. Lowered temperatures at these horizons and the diffusion of CO_2 from the mineralizing solutions into ground waters at these horizons and in the overlying sandstones, upset the existing equilibrium and resulted in deposition of fluorite. The physical-chemical conditions prevailing in the Downey's Bluff, "Renault limestone" and in the Fredonia limestone were more favorable for the deposition of fluorspar than were the conditions which prevailed at the Levias limestone horizon.

BIBLIOGRAPHY

1. American Journal of Science, 1st series; Volume 1, pp 52-53, 1818; Volume 2, p. 178, 1820; Volume 3, p. 243, 1821.

2. Atherton, Elwood. "Some Chester Outcrop and Subsurface Sections in Southeastern Illinois". Illinois Acad. Sci. Trans., Volume 40, p. 129, Illinois State Geological Survey Circular 144.

3. Bain, H. F. "Fluorspar Deposits of the Kentucky-Illinois District". Mines and Minerals, Volume 25, No. 4, pp 182-183, November, 1904.

4. Bain, H. F. "The Fluorspar Deposits of Southern Illinois". U.S.G.S. Bulletin 255, 1905.

5. Bastin, E. S. "The Fluorspar Deposits of Hardin and Pope Counties, Illinois". Illinois State Geological Survey Bulletin No. 58, 1931.

6. Brush, G. J. "Note on the Fluorspar Locality of Gallatin County, Illinois". Amer. Jour. Sci., 2nd series, Volume 14, p. 112, July, 1852.

7. Currier, L. W. "Origin of the Bedding Replacement Deposits of Fluorspar in the Illinois Field". Econ. Geol., Volume 33, No. 3, pp 364-386, 1937.

8. Currier, L. W. "Structural Features of the Illinois-Kentucky Field". Wash. Acad. Sci. Jour., Volume 25, No. 11, pp 505-506, November 15, 1935.

9. Currier, L. W. and Wagner, Jr., O. E., "Geology of the Cave in Rock District". U.S.G.S. Bulletin 942, 1944.

10. Emmons, S. F. "Fluorspar Deposits of Southern Illinois" Trans. Am. Inst. Min. Eng., Volume 21, pp 31-53, 1893.

11. Hardin, G. C. and Thurston, W. R. "Celestite from Livingston County, Kentucky". Am. Min., Volume 30, No. 9 and 10, p. 639.

12. Schoolcraft, Henry R. "A View of the Lead Mines of Missouri". New York, p. 191, 1819.

13. Schoolcraft, Henry R. "Travels in the Central Portions of the Mississippi Valley". U.S.I.A., New York, pp 189-196, 1825.

14. Schwerin, M. "An Unusual Fluorspar Deposit". E.&M.J., Volume 126, No. 9, pp 335-339, Sept. 1, 1928.

15. Shand, S. James. "Eruptive Rocks" Second Edition, John Wiley and Sons, New York, 1943.

16. Spurr, J. E. "The Kentucky-Illinois Ore-Magmatic District". E.&M.J., Volume 122, No. 18, pp 695-699, Oct.30 1926; Volume 122, No. 19, pp 731-738, Nov. 6, 1926.

17. Sutton, A. H. and Weller, J. M. "Lower Chester Correlations in Western Kentucky and Illinois". Jour. Geol. Volume 40, No. 5, pp 430-439, 1932.

18. Swann, D. H. and Atherton, E. "Subsurface Correlations of Lower Chester Strata of the Eastern Interior Basin". Illinois State Geological Survey, R.I.No.135, p. 270,1948

19. Tippie, F. E. "Insoluble Residues of the Levias and Renault Formations in Hardin County, Illinois". Illinois State Geological Survey, Circular No. 102, pp 155-157, 1944.

20. Tippie, F. E. "Rosiclare-Fredonia Contact in and adjacent to Hardin and Pope Counties, Illinois". A.A.P.G., Volume 29, No. 11, p. 1658, November, 1945.

21. Ulrich, E. O. and Smith, W. S. Tangier. "Lead, Zinc, and Fluorspar Deposits of Kentucky". U.S.G.S. Professional Paper, No. 36, p. 18, 1905.

22. U.S.B.M., War Minerals Report No. 118, "Zinc-Fluorspar Property of the Minerva Oil Company, Cave in Rock, Hardin County, Illinois".

23. Weller, Stuart. Kentucky Geological Survey, Series 6, Volume 4, pp 27-30, 1921.

24. Weller, Stuart, Butts, Charles, Currier, L. W., and Salisbury, R. D. "The Geology of Hardin County". Illinois State Geological Survey, Bulletin 41, 1920.

25. Workman, L. E. "Subsurface Stratigraphy of Cypress to Fredonia Formations in the Illinois Basin". February 4, 1938, Mimeographed.

26. Worthen, A. H. and Engelmann, George. "Geology of Illinois, Hardin County". Geological Survey of Illinois, Volume 1, pp 350-375, 1866.

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